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Simulation studies on performance of solar cooling system in UAE conditions

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Abstract

The abundance of solar radiation makes the approach of solar cooling the most sustainable cooling solutions for the Gulf countries like UAE. In this article, the performance of a 10 TR solar absorption cooling system was evaluated by TRNSYS simulation. The system used for simulation studies was developed at SOLAB of CSEM-uae for the purpose of assessing the potential of applying solar cooling systems in this region. Simulation results show that the solar cooling system operates with a COP in the range of 0.60 – 0.80. The simulation results closely match a typical day performance validating the model. The currently installed system can meet its cooling requirement for almost 2/3[rd] of year without back up heating and/or cooling.

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Keywords : Solar Cooling; Vacuum Tube Collectors; TRNSYS Simulation; UAE region

1. Introduction

Due to hot and humid climate in this region, characterized by high ambient temperatures especially during the summer, buildings require intensive cooling to provide comfort conditions. The peak cooling demand in buildings occurs during periods of high ambient temperatures and high solar insolation; peak radiation is of about 1000 W/m^2 and an average of 550 W/m^2 [1], which is in phase with solar cooling potential. This indicates a huge potential of

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applying solar assisted or driven cooling systems in this country. In this article, the performance of a 10 TR solar absorption cooling system was evaluated by Transient System Simulation (TRNSYS) [2] software. The system used for simulation studies was developed at Solar Laboratory (SOLAB) of, the Swiss Center for Electronics and Micro Technology (CSEM) in The United Arab Emirates (CSEM-uae) for the purpose of assessing the potential of applying solar cooling systems in this region.

Nomenclature

CHW_{in}	chilled water chiller inlet
COP	coefficient of performance
COP_t	thermal coefficient of performance
CW_{in}	cooling water chiller inlet
CW_{out}	cooling water chiller outlet
EXP.	Experiment
G	global incident radiation
HW_{in}	hot water chiller inlet
HW_{out}	hot water chiller outlet
Q_{CHW}	chilled water thermal power, kW
Q_{CW}	cooling water thermal power, kW
Q_{HW}	hot water thermal power, kW
$Q_{incident}$	incident solar power on collector surface, wm^{-2}
SFC	solar fraction cooling
T	temperature, °C
TMY2	typical metrological year 2
TR	tons of refrigeration
TRN.	TRNSYS
θL	transverse incidence angle
θT	longitudinal incidence angle
η	efficiency

1.1. Objective

The overall objective of the research started by CSEM-uae in solar cooling is to evaluate the techno-economic potential of the solar cooling systems in UAE/Gulf region. As a part of the overall objective this article covers the specific objectives of simulation performance assessment of solar cooling system model developed by mimicking the existing facility along with validating the model with a typical day experimental results. Furthermore, it also covers identifying factors for improvement in the performance.

1.2. System description

Fig. 1. Snapshot of CSEM-uae solar cooling R&D facility at SOLAB in Ras Al Khaimah-UAE.

The developed solar cooling system consists of a single effect vapour absorption chiller, with a rated cooling capacity of 35.2 kW, thermally powered by 128 m^2 gross area of vacuum tube solar collectors. The collector system consists of 8 collector arrays in parallel having 4 collectors in series in each array. A 1000 liter capacity storage tank integrated with spherical heat exchanger is used for stratified charging hot water. The storage capacity is extended with an additional 1000 liter back up tank. The chilled water generated is stored in an another 1000 liter back up tank and distributed through Fan Coil Units (FCUs) to three cabins and one tent to meet the cooling demand. The heat rejected from the chiller is dissipated to the environment with the help of an induced draft counter flow wet cooling tower. Water is used as heat transfer fluid in collector, storage, distribution and rejection circuit.

1.3. Meteorological profile of the location

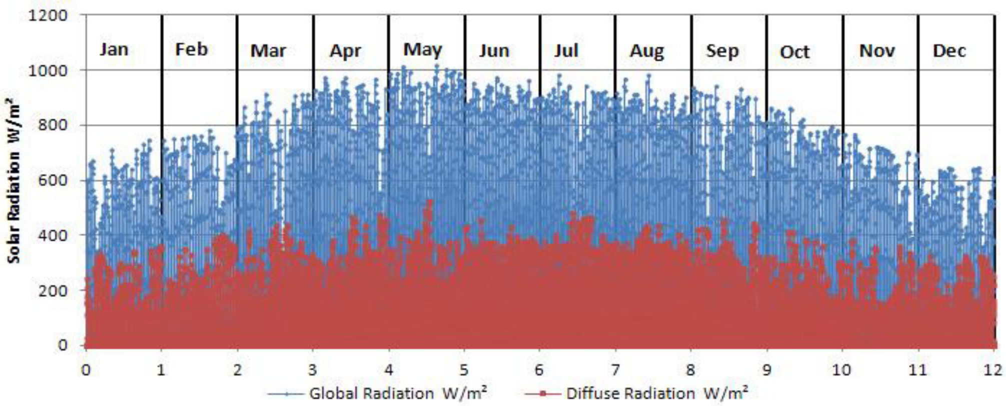

Fig. 2. Hourly variation of solar radiation at SOLAB of CSEM-uae in Ras Al Khaimah-UAE

The location can be characterized as having abundant solar energy resources with the peak global radiation close to 1000 W/m^2 as shown in Fig. 2 during the months of May. The summer month ambient is characterized as having temperature with a peak close to 45°C and average humidity is close to 55 % as shown in Fig. 3.

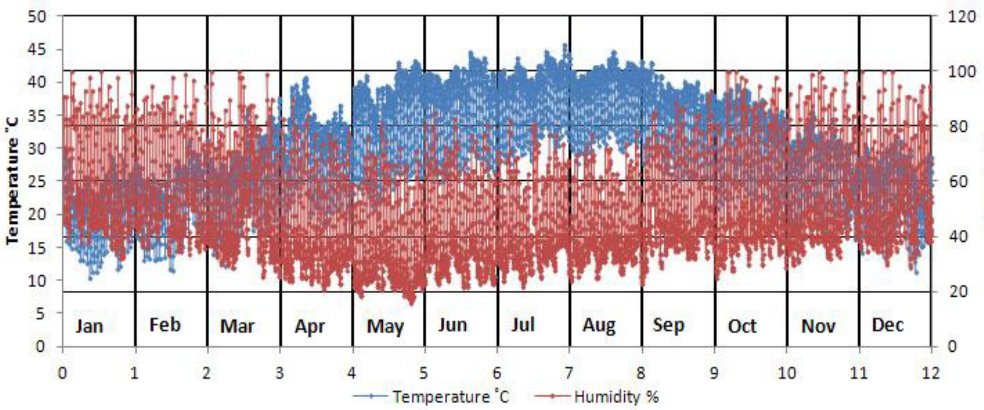

Fig. 3. Hourly variation of temperature and humidity at SOLAB of CSEM-uae in Ras Al Khaimah-UAE.

2. Simulation description

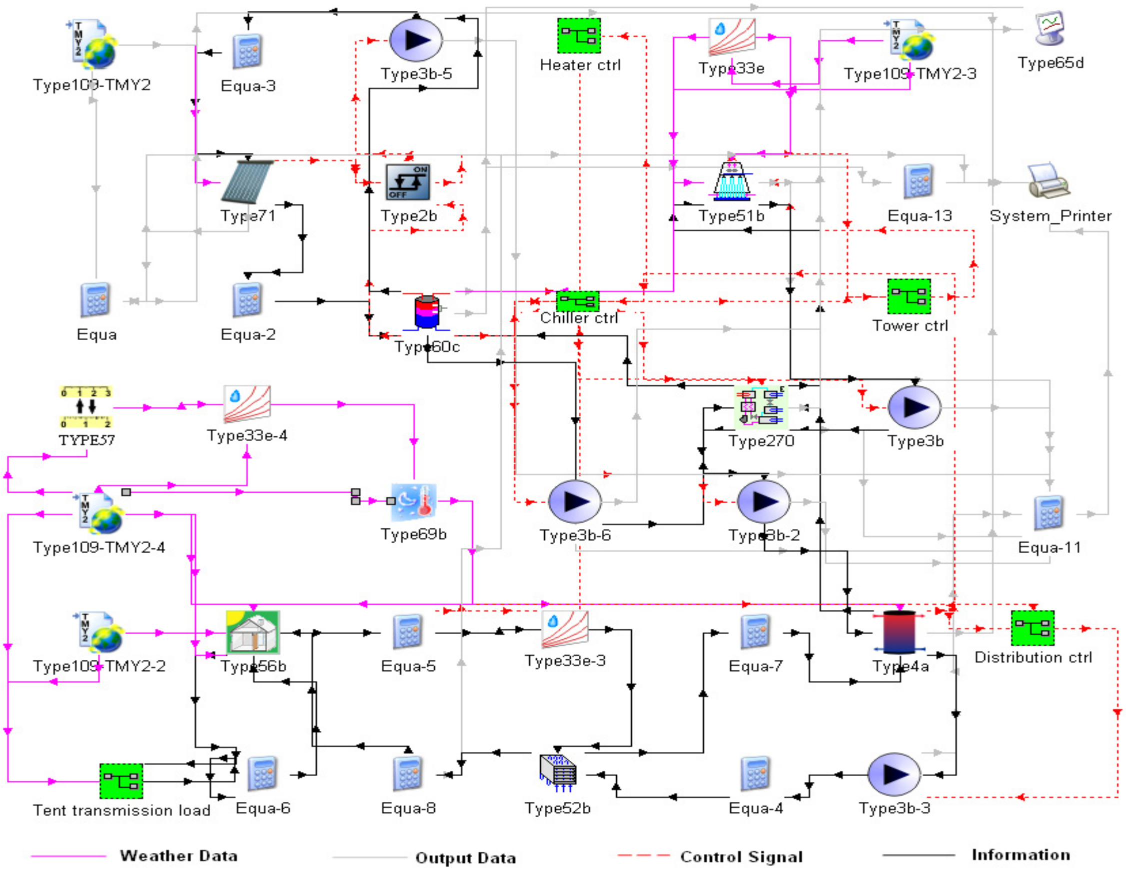

Fig. 4. Simulation project snapshot

TRNSYS was chosen for modelling of the solar cooling system components and performance of the overall system. This software enables use of inbuilt models (Types), whose inputs and outputs are connected to generate a simulation project. One major advantage TRNSYS has is its ability to allow users develop new non existing models that best suit the physical phenomena being modelled. The simulation project snapshot is shown in Fig. 4.

Type 71 models the performance of an Evacuated Tube Collectors (ETC). The collector efficiency model (1) considers efficiency curve coefficients η_0, a_1 and a_2 as 0.73, 1.5 W/m^{2}K and 0.0054 W/m^{2}K respectively [3].

$$\eta = \eta_0 - a_1\left(\frac{T_{average}-T_{ambient}}{G}\right) - Ga_2\left(\frac{T_{average}-T_{ambient}}{G}\right)^2 \tag{1}$$

Type 60c models stratified hot water tank by specifying a given number of temperature nodes in the tank, N, where$1 < N \leq 15$. For N=1, the tank models as fully mixed type. Type 51b, 52b and 3b model the wet cooling tower, FCUs and circulation pumps respectively. Similarly, the chiller was modeled, using a user incorporated model, Type 270, which was based on chiller performance mathematical model developed by K.T. Whitte et al. [4]. Use of Type 270 required generation of the performance data of the chiller based on the inlet cooling and hot water temperatures [5]. Type 56 multizone building simulation help models the cooling loads. Controllers for solar collector field, stratification, chiller, cooling tower fan and chilled water distribution were implemented mainly based on Type 2b control models and equations were included in the simulation to closely mimic the physical phenomenon. All mathematical models of the inbuilt Types used in the prescribed simulation projects are described in the TRNSYS user manual, the TRNSYS Mathematical reference manual [6].

To assess the performance of the solar cooling system, equations 2–4 were used for computation of Thermal Coefficient of Performance (COP_t), Solar Fraction Cooling (SFC) and Specific collector yield respectively [7].

$$COP_t = \frac{Q_{CHW}}{Q_{HW}} \tag{2}$$

$$SFC = \frac{Total\ chilling\ energy\ of\ the\ system}{Total\ cooling\ requirement} \tag{3}$$

$$Specific\ collector\ yield = \frac{Thermal\ energy\ gain\ [kwh]}{Collector\ area\ [m^2]} \tag{4}$$

3. Result and discussion

3.1. Cooling supply and demand assessment

The cooling demand of three cabins viz: SC, PV and SI and one tent (TENT) was estimated for a typical working day of 0800 to 1800 for an indoor set point temperature of 22°C. The total floor area of three cabins was 91.75 m^2 and tent 25 m^2. Occupancy of 1 person per 10 m^2 of floor area and a personal computer with 140 W color monitor for each person along with metabolism heat dissipation rate of the occupants following ISO 7730 standard was used [8]. Infiltration rates of 0.5 ACH and 0.7 ACH were considered for all cabins and TENT respectively.

Fig. 5 shows that May to September register the highest cooling demand with the SC cabin registering maximum round the year because of its larger floor area. Fig. 6 shows system's SFC and specific collector yields. The installed system has the capacity of meeting the cooling demand of eight months (with SFC ≥ 1.0) except June, June, July, August and September. However, the specific collector yields are higher for these four months due to the high solar insolation characterizing this period.

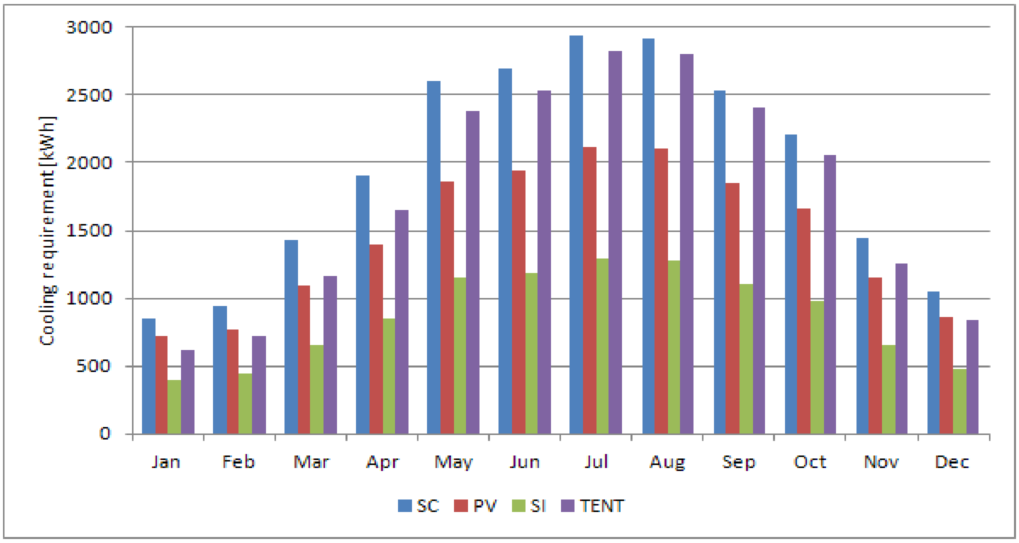

Fig. 5. Cooling demand of different thermal zones

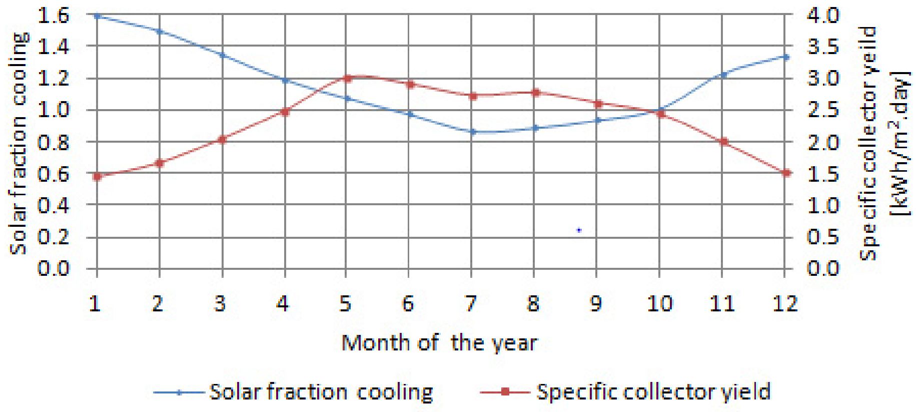

Fig. 6. Solar fraction cooling and specific collector yield.

3.2. Thermal COP of the system

Fig. 7 shows the hourly variation of the COP of the solar cooling system for a year. The COP lies in the range, 0.60 – 0.80 with an average of 0.70. However, more variations in COP are observed during the winter periods (i.e. 0 – 3624 & 6552 – 8760 hrs) than summer periods. Fig. 8 shows the hourly variation of the instantaneous system chilling and generator power for a year. It is observed that the peak chilling and generator thermal powers are higher for winter periods than summer periods. This can be attributed to the high cooling temperatures due to the high ambient temperatures during the summer periods. Optimization of the performance of the wet cooling tower during the summer periods is highly recommended.

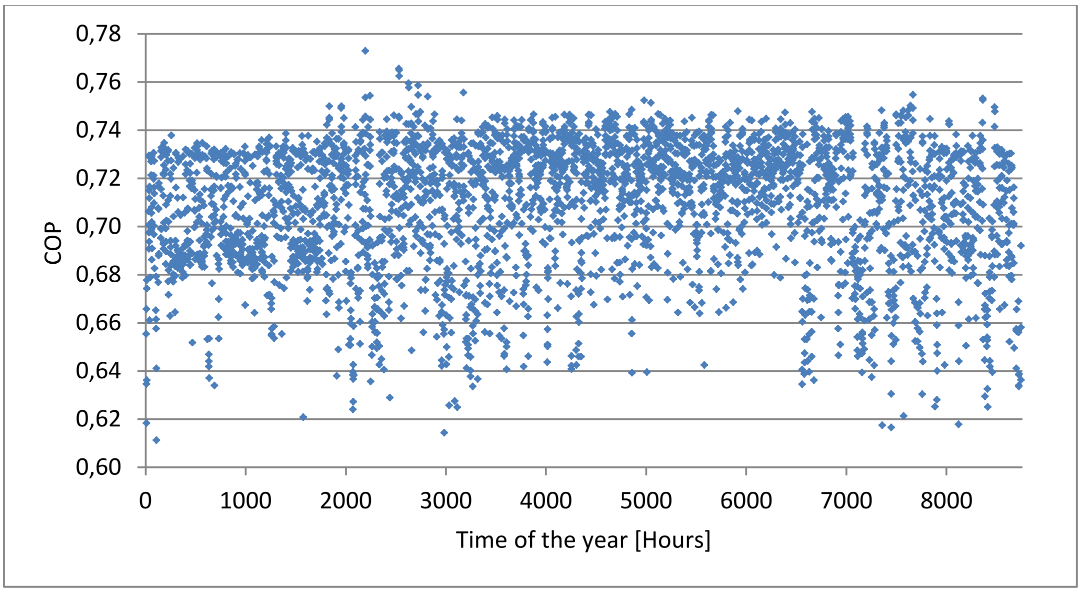

Fig. 7. System thermal COP versus time of the year.

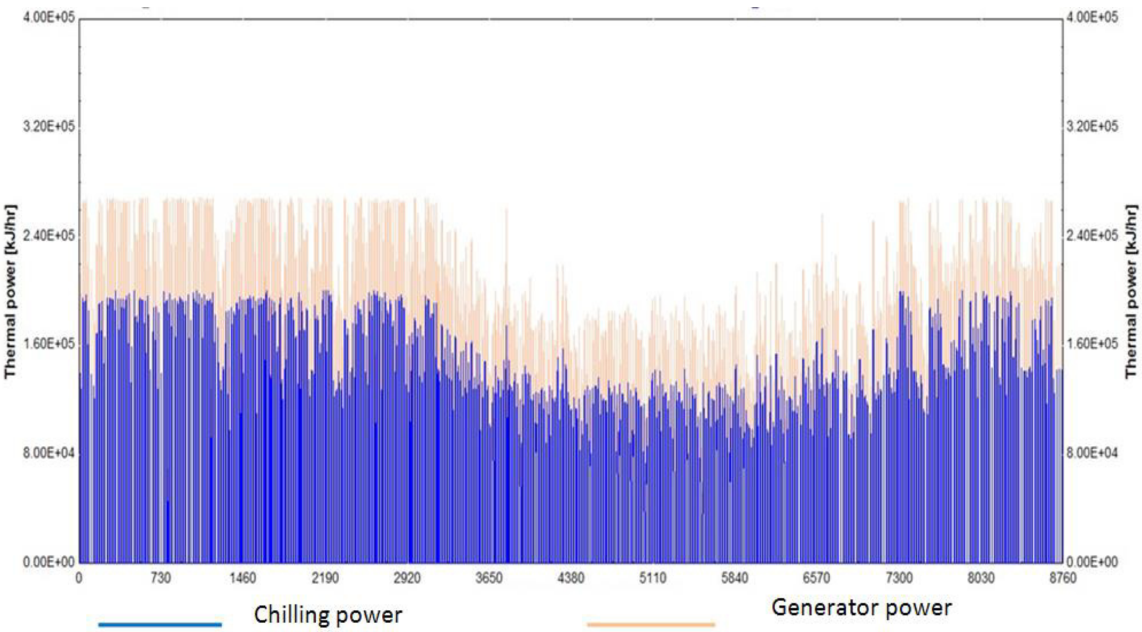

Fig. 8. Instantaneous generator power versus chilled power.

3.3. A generic validation of the simulation

A typical day performance comparison between experimental and simulation result of the solar cooling system for April is presented in Fig. 9 and 10. Incident radiation trend from simulation matches closely with the measured value. However, thermal COP_{EXP} is slightly less than COP_{TRN} particularly during start up period. It is observed that the start-up period is having high chilled water inlet temperature, less hot water inlet temperature and higher cooling water inlet temperature, consequently resulting for less COP_{EXP} at the start-up. The fluctuation in the COP_{EXP} through-out the day seems following the fluctuation with the cooling water inlet temperature. Less value of inlet hot water temperature throughout the day shows further requirement of improvement of the model from the perspective of heat loss of storage tank and piping.

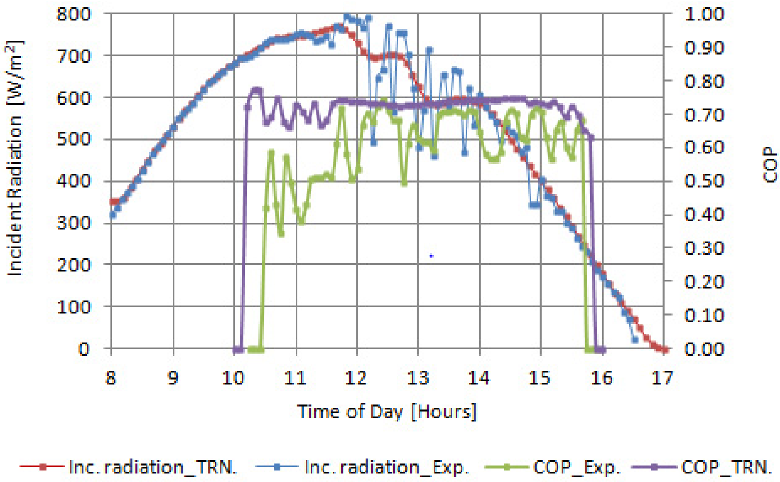

Fig. 9. Performance comparison for a typical day in April

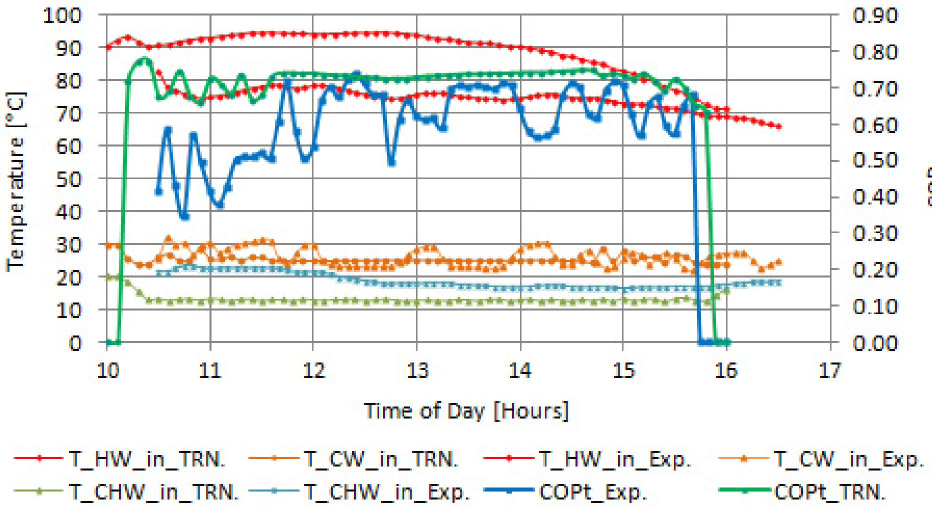

Fig. 10. Performance comparison for a typical day in April

In overall, the trends of experimental values are close to TRNSYS simulation and a sudden change of performance governing factors seems reflected in the overall performance. However, a further closer approximation to the physical behavior of various components at start-up is needed. In summary, the developed modeling platform could be applied for the generic prediction of the solar cooling performance in UAE.

3.4. A typical summer day performance prediction

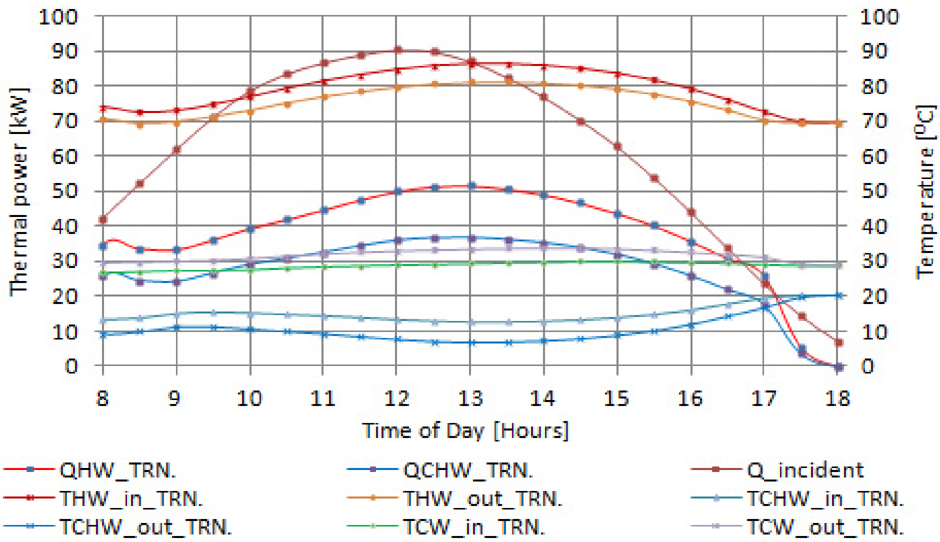

Fig. 11. Performance prediction for a typical day in June

A typical summer day simulation performance of the solar cooling system considering the month of June is presented in Fig. 11. A smooth operation of the absorption chiller is observed because the cooling requirement is slightly higher than the chilling capacity of the system. The peak chilling power output and generator heat input power is less during the summer compared to winter because of the influence of a higher cooling temperature.

3.5. Factors to improve the SFC

Fig. 12, 13 and 14 show the effect of total collector area, collector tilt, collector fluid flow, chiller start temperature, chilled tank environmental temperature and heat loss coefficient and incorporation of auxiliary heater in the stratified tank to improve the SFC for the months June – September. From Fig. 12 (a), it is evident that a collector gross area of 150 m^2 is sufficient to meet the cooling requirements of all the months including the months of June – September even without incorporation of an auxiliary heater or changing the chiller chilling capacity. Furthermore according to Fig. 12 (b), a collector slope of 15° maximizes the average SFC for June – September.

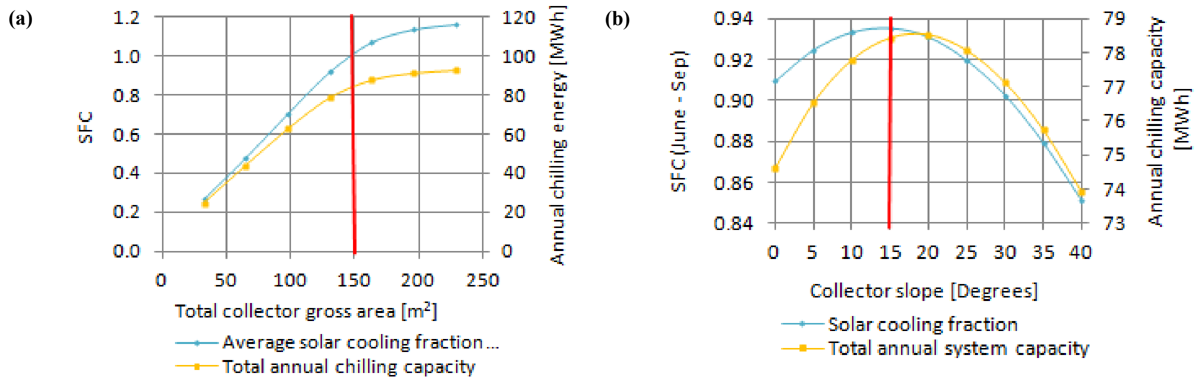

Fig. 12. (a) Effect of total collector area on SFC; (b) Effect of collector slope on SFC

Fig. 13. (a) shows that a water flow vrate of 180 l/h maximizes the average SFC for the month of June – September. However, there is a very small difference between the average values of SFC for the months of June – September for a flow rate between the ranges of 150 – 200 l/h; hence a value with in this range is sufficient. Fig. 13 (b) indicates that a chiller start temperature of 78°C is optimum for maximization of the June – September average SFC. Installation of a controller between the absorption chiller and the stratified tank that ensures chiller starting to be at a hot water temperature close to 78°C is highly recommended.

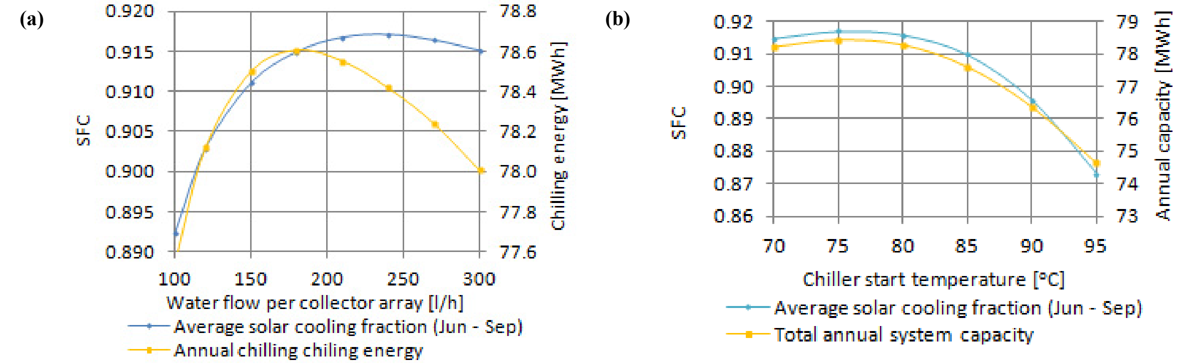

Fig. 13. (a) Effect of water flow per collector array on SFC; (b) effect of chiller start temperature on SFC

Fig. 14 (a) suggests that the installation of the chilled water tank indoors has a great benefit especially for cases of improper insulation (high loss coefficients) of the tank. Lastly, according to Fig. 14 (b), an incorporation of an auxiliary heater of capacity at least 15 kW in the stratified thermal storage tank can help meet the cooling demand.

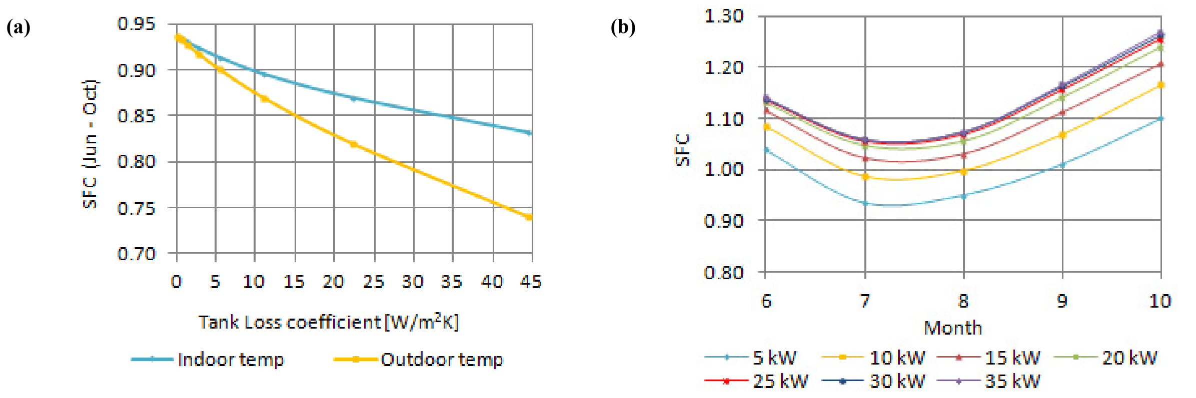

Fig. 14. (a) Effect of chilled water tank loss coefficient on SFC; (b) Effect of chiller start temperature on SFC

4. Conclusion

Simulation results show that the solar cooling system is operated at optimum COP and the chilling capacity is sufficient throughout the year except June-September due to low SFC. The low SFC for the months of June-September can be improved either by increasing the total gross area to 150 m^2, or maintaining a water flow to the collector arrays in the range 150 – 200 l/h, or maintaining a chiller start temperature of 78°C, or by incorporation of an auxiliary heater in the stratified tank. This study shows that solar cooling in UAE has very huge potential for replacement of the conventional fossil powered air-conditioning systems. Experimental along with economics of scale studies are currently under progress to compare results with that of simulation studies.

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